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Board 74: Work-in-Progress: Containing Design: Rethinking Design Instruction to Support Engineering Device Development for Low-Income Countries

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Work-in-Progress: Containing Design: Rethinking Design Instruction to Support Engineering Device Development for Low-Income Countries

Abstract

Work-in-Progress: One of the primary benefits of a makerspace is the concentration of tools, materials, and expertise in one place [1]. Without makerspaces, design education in many low- to middle-income countries (LMIC) stops with a "paper" design and does not move onto a physical prototype. More than 75% of registered makerspaces are in North America and Europe [2], and less than 4% of registered makerspaces are in Africa [3].

As part of a joint project between Duke University (NC, USA) and Makerere University (Kampala, Uganda), "twin" makerspaces were built at the respective universities. At Makerere, this makerspace was a first at the university and has transformed engineering design practice. At Duke, the makerspace has supported resource-constrained design, a necessary component for producing products for LMIC markets.

At Makerere, the DesignCube is an engineering makerspace built from two shipping containers, which are abundant in East Africa. The DesignCube includes furniture (tables, chairs), tools (electrical, woodworking, sewing machine), and locally available materials (wood, metal, cardboard, plastics). The layout of the DesignCube allows for 20 students to comfortably prototype, collaborate, and learn. The space was inaugurated in June 2022 with a joint Duke-Makerere summer design internship. During the 2022-2023 academic year, Makerere biomedical engineering students are completing their design projects in the DesignCube.

Duke design teams in the first-year design course designed and constructed the Duke DesignCube, which has a fully furnished interior, with tables, tools, and materials. Note that the tools and materials placed at Duke mirror the ones in Makerere and do not include items such as laser cutters, 3D printers, etc. Additionally, the DesignCube has a system of solar panels and related battery storage. The Duke DesignCube uses only one container, so outdoor workspace around the container is used to accommodate 20 students. For four semesters, Duke student teams have prototyped in the DesignCube (rather than Duke's large, well-furnished makerspace) on design projects with intended use in LMICs.

On the Duke side, early assessment focused on identifying which tools and materials the teams wanted for their project, but were unavailable in the DesignCube. These surveys identified many specific electrical components, which were available in the USA, but not in Uganda. Otherwise, students were able to work comfortably and produce prototypes at the low- and medium-fidelity levels, but not at the high-fidelity level. On the Makerere side, students also ran into limitations, especially when creating high-fidelity prototypes. Trips to the local markets supplemented the materials in the DesignCube. Surveys completed by Duke students during the summer design internship reveal their appreciation of the value of practical ingenuity and how unexpected materials can be used to create functional prototypes.

Role of Making in Design Education

Simply defined, a makerspace are community centers with tools [4]. Several terms for making spaces have evolved from Fab Labs to Hackerspaces. Hira separates makerspaces from other places for making with the definition: "Makerspaces combine manufacturing equipment, community, and education to enable community members to design, prototype, and create manufactured works that would not be possible to create with the resources available to individuals working alone" [4]. Hira also presents a conceptual framework through which to analyze the organization of different makerspaces. This framework includes three central aspects of makerspaces (people, means, and activities) connected via the makerspace's purpose. People are those that use, support, run, or interact with the space. Means are the artifacts that determine the capabilities of the makerspace (tools, materials, infrastructure, etc). Activities are the actions taken by the people using the means. This framework can be used to characterize makerspace operation by weighing the role of each aspect. A people-focused makerspace, for example, will evaluate the needs of the community and use that to guide development of activities and expansion of means. In contrast, a means-focused makerspace may choose to procure cutting-edge additive manufacturing technology. People attracted to these means will become the makerspace community and determine activities through use of the high-tech means.

The study of makerspaces arose along with the rise of the 'Maker Movement,' which began in the early 2000s. MIT was the first institute of higher education to create a makerspace, and today they have a 28-space 'MakerSystem' [5]. These spaces allowed groups of makers to use prototyping technologies without having to purchase individual machines or licenses. The movement soon became popular in formal and informal settings as a convenient way to build projects. The rise of makerspaces as environments for independent building and prototyping has become common within engineering education in the United States. Today there is a prolific section of literature devoted to makerspaces at institutes of higher education [5] and makerspaces can be found in the news as the source of the next manufacturing revolution [6].

Makerspaces as a locus for design learning is a topic that has received extensive attention. The theory of maker education relates to many educational frameworks, including Piaget's constructivism theory [7], the Situated Learning Model [8], and Community of Practice [9], all of which have been applied to understand learning in a makerspace [10]. The style of learning and appropriate frameworks depend highly on the type, location, and use of a makerspace.

Experience working in a makerspace improves creativity [11], collaboration in diverse teams [12], design self-efficacy [13], and technical skills used in industry [12]. Agency is an important component of a makerspace [4]. Students are typically free to choose what, how, and why to build.

Accessibility and equity are tenets of the maker movement, and many makerspaces have mottos that highlight them as a space for all. This open environment can provide freedom to those unaccustomed to making. Makerspaces have even been shown to be a valuable participation pathway [15] and to increase design confidence for women in engineering [14]. However, diversity and inclusion issues still exist within makerspaces [14]. The types of making that are championed in makerspaces are typically those associated with men [15] and Western making traditions.

The growth of makerspaces as an educational tool and resource has not spread across the world at the same rate. More than 75% of registered hackerspaces (a makerspace focused on computer science) are in North America and Europe [2] and less than 4% of registered Fab Labs (makerspaces focused on fabrication and physical making) are in Africa [3]. The makerspaces that exist in low- and middle-income countries of similar organization to high-income makerspaces support student skill development at similar rates [10], despite the challenges of a low-resource setting. A study of a mobile makerspace in Nigeria had difficulty achieving constant power, training users, and securing the space [16]. Despite slower growth, the maker movement is on the rise in Africa. The Africa Makerspace Network, a consortium of makerspaces, was founded in 2019 and currently has 27 members [17].

Limitations of Making at Duke University and Makerere University

In this section, we discuss making education at two partner universities: Duke University in the USA and Makerere University in Uganda. Engineering students at Duke University take their first engineering design class [18], as well as other project-based courses, in a 3,000-ft^2 makerspace (Figure 1). Students have access to low-fidelity prototypes such as pool noodles, straws, and duct tape, as well as medium/high fidelity tools such as 3D printers, woodworking tools, microcontrollers, and laser cutters.

The incredible resources in Duke's makerspaces enable nearly limitless prototypes, but this does not always produce the best designs. When students in the first year design course work on problems from LMICs, they often lack an understanding of the environment and context of the problem. For example, a typical design specification is that the design solution should be replicable in an LMIC, which requires using only materials and manufacturing techniques available in LMICs. However, students at Duke often use 3D printers on their design. When the instructor questions the choice to use such a technology, as 3D printing is not readily available in LMICs, students reply, "It's only a prototype." As the design progresses, 3D printing becomes integral to the design. While the final design works, it is inappropriate for the context. The students may have learned to make technical, high-fidelity prototypes, but they did not fully develop an understanding of context and application of their designs.

The implications of this lack of contextual understanding can be significant. In the case of medical devices, the lack of effective and appropriate biomedical technology is a major factor in the global health disparity. Traditionally, most of the medical technology in LMICs consists of inappropriate devices sent from developed countries. Main problems with health technologies are prohibitive price, high electricity demand, complex operation, lack of replacement parts, and high maintenance [19]. These technologies, like the 3D-printed prototype in first-year design, work well in High Income Countries (HICs), but fail in LMIC contexts. The challenge of teaching design for specific LMIC contexts in HICs becomes integral to developing successful medical devices.

Figure 1: Duke Design POD (2020) *Figure 2: Makerere Design Workshop (2020)*

At Makerere University, engineering design looks very different. Previously, the design and laboratory space was a small room with broken biomedical equipment (Figure 2). There are no prototyping tools or supplies. Makerere's biomedical engineering program contains a required capstone design course, but the students had limited ability to prototype their designs. Final prototypes were a mix of 1) "paper" models including CAD and drawings, and 2) prototypes made from local craftsmen who followed the "paper" models during constructions. Students sourced prototyping services, tools, and materials from nearby private workshops at their own cost. Iterations, including incorporating testing results into an updated design, were rare.

The lack of prototyping opportunity at Makerere also contributes to the lack of appropriate medical devices in LMICs. The World Health Organization (WHO) highlights limited trained staff, lack of necessary skills, and limited support as key barriers to manufacturing medical devices locally in LMICs [20]. Even trained engineers, like graduates of Makerere, often lack practical design and prototyping experiences. In an investigation of product manufacturers in East Africa, "no coherent design processes were observed" [21]. The product designers in the study focused on reproducing foreign designs instead of creating new designs.

In summary, the design experience at Duke suffers from a knowledge gap where the problem context is missing, while the experience at Makerere has a technology gap where the prototyping tools and spaces are missing. The authors of this paper realized that these gaps could be filled by forming a partnership and solving these problems collaboratively. Their solution was a makerspace appropriate for the LMIC environment. In 2019, the authors secured a $30,000 VentureWell faculty grant to design and construct a "twin" makerspace on each campus. To accommodate the needs of Makerere's space, metal shipping containers were chosen as a cheap, modular, and durable building material. The rectangular prism shape of a container and focus on design learning led the team to name the makerspaces "DesignCubes."

The project provided opportunities to explore both individual and joint research questions. Makerere has been able to observe the impact of a first-of-its-kind DesignCube on its students' prototyping abilities. Duke's DesignCube purposefully limits access to certain technologies to mimic the environment of a LMIC. This allowed the Duke team to examine changes in prototyping processes when students use the container makerspace. Jointly, the teams have explored the possibilities of shipping container makerspaces to identify best practices. Each makerspace has its own design unique to its environment, and comparing the differences will enable optimized designs for future makerspaces. Since the DesignCubes were completed, students from Duke have worked in both DesignCubes and Makerere students have worked in their DesignCube.

Building the DesignCubes

Duke DesignCube

The DesignCube at Duke is constructed from one 40 ft x 8 ft shipping container with the intention of accommodating 10-20 students. The design of the makerspace was a broken into two main projects in the first-year design course over two academic years; one team worked on making the container into a functional makerspace (layout, tools, and materials), and the other team worked on providing solar power to the DesignCube.

The makerspace function team designed several layouts and quickly determined that the interior space (only 320 ft^2 floor space) could only hold two to three teams, meaning that others would need to work outside. So, an outdoor/indoor workspace was proposed; this idea was well received as many activities occur outside in Uganda during the dry season. The final layout (Figure 3) houses three teams inside the container and two outside. The storage space is concentrated on one wall, with two cubby cabinets (backpacks, prototype storage) and three console cabinets (prototyping supplies, tools). A large pegboard (11 ft long, 4 ft tall) stores the majority of tools for easy identification by students. No windows or doors were cut into the DesignCube.

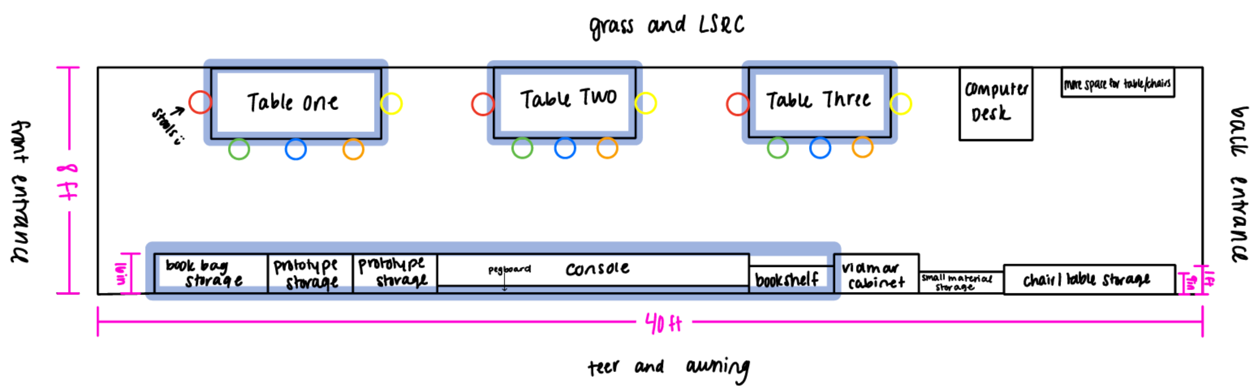

Figure 3: Duke DesignCube Layout Schematic

The outdoor workspace is created with a retractable awning on the long side of the container. The awning uses a fixed PVC frame with retractable and removable tarp coverings for shade and weather protection (Figure 4). This awning design does not require support from the ground and was built in four 10 ft sections.

Figure 4: Retractable Awning

To generate power to the Duke DesignCube, two 300 W solar panels are fixed on top of the container (Figure 5). They feed deep-cycle batteries for a total storage of 2.5 kWh. An AC inverter supplies 120V power to five outlets

Figure 5: Solar Panels

Figure 6: Batteries and Solar Control System

along the interior of the container. The solar controllers, batteries, and AC inverter are mounted inside the container (Figure 6).

The prototyping tools and materials for the Duke DesignCube were selected based on commonly used tools in other Duke makerspaces. The list of tools and materials (Appendix A) was crosschecked by Makerere faculty. All the tools are basic hand tools with the exception of a battery-powered drill and a sewing machine. Pegboards are a common makerspace feature because they make tools easy to locate. A hanging pegboard holds all tools in the DesignCube. The materials range from low-fidelity craft materials to cardboard, wood and PVC to electronics. Scavenged materials are also commonly used in the DesignCube. Makerere engineering students often involve recycled and scavenged materials in their lower-fidelity designs, so the materials in the DesignCube try to encourage this practice.

Construction of the Duke DesignCube cost approximately $10,000, with the procurement of a shipping container as the highest expense. The shipping container, modifications to add a garage door and vents, and transportation to Duke campus cost approximately $5,000. Tools, tables, and materials were scavenged or taken from other makerspaces on campus.

Makerere DesignCube

The DesignCube is made of two conjoined shipping containers, with a total footprint of 40 ft x 16 ft (Figure 7). Figure 8 displays the internal layout. The first shipping container is not sectioned, and it contains four tables that serve as working stations for the design teams (Room 4). The second shipping container is sectioned into three rooms: the space manager's office (Room 1) and a storeroom (Room 3) that are 10 ft x 8 ft each, and a fabrication space of 20 ft x 8 ft accommodating the tabletop equipment and the rest of the openly accessible tools (Room 2).

Figure 7: Exterior of Makerere DesignCube

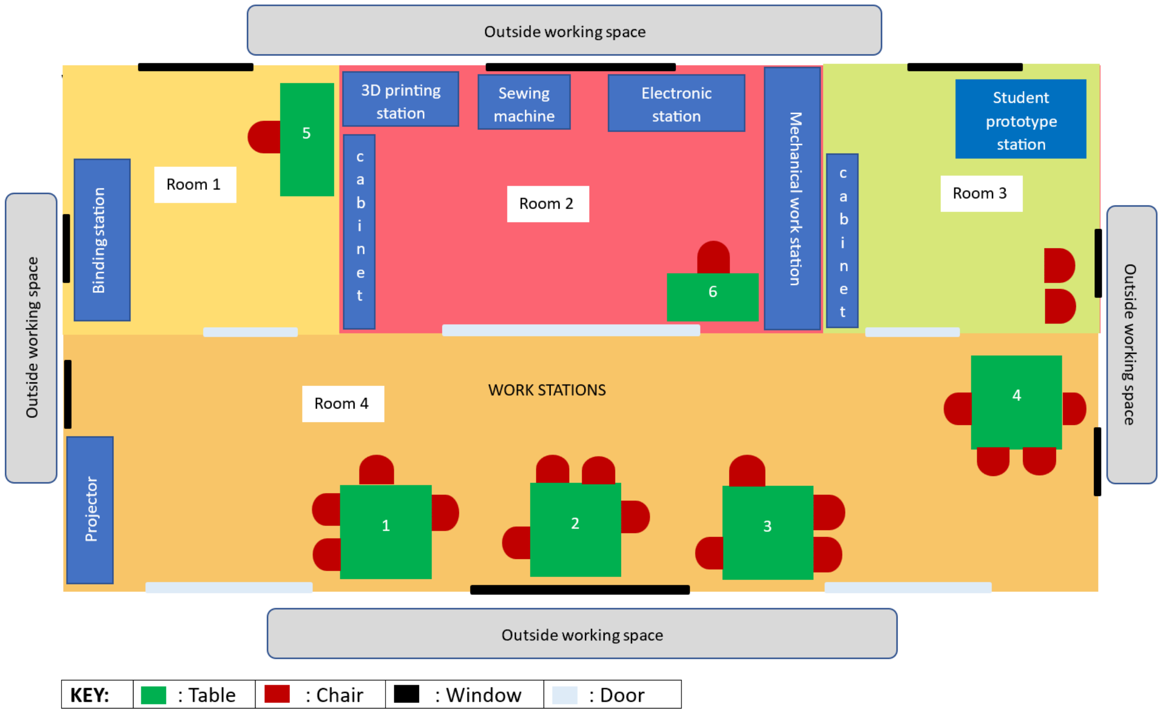

Figure 8: Makerere DesignCube Schematic

To improve airflow the DesignCube has two large doors in the front (5 ft X 6 ft each) and 4 ft X 4 ft windows. At the back, each sectioned room has a 3 ft X 4 ft window and with small windows the sides of the container. The Makerere DesignCube has a variety of materials and tools that can be used for electrical and mechanical work. These tools include a sewing machine, a clamp, vices, and hand tools like saws, solder gun and wires, screws, wrenches, and hammers. A partial list is included in Appendix B.

The Makerere DesignCube cost ~$15,000. Costs included building a foundation, purchasing two containers, joining the containers and adding windows, and constructing a roof and porch. Money was also spent to purchase tools.

Implementation

Duke DesignCube

The Duke DesignCube was completed in Fall 2020 and has been used by several design teams in the last five semesters. The primary use of the Duke DesignCube is as an alternate makerspace for the first-year design course (EGR101) and EGR102: Design to Delivery. Teams with projects intended for LMIC environments prototype in the DesignCube instead of the usual classroom (Figure 1). Past DesignCube projects include:

- Portable neonatal incubator. The wooden frame and handles of the device were prototyped in the DesignCube.
- Supports to convert a hospital exam table into a delivery bed. Components to hold the legs, raise the back/trunk, and handrails were constructed.

- Modular UV light stand to treat neonatal jaundice. A portable, adjustable stand was built using PVC.
- Water velocity monitoring system for Kenyan irrigation canals. An integrated electronic and mechanical device was built.

Student teams use the DesignCube for the second half of the semester when most class time is spent prototyping (Figure 9). Each team adds new context to the DesignCube designs and the value of these spaces.

Figure 9: Students working in and around the DesignCube

Makerere DesignCube

The Makerere DesignCube was delayed by the pandemic and was completed in 2022. The DesignCube at Makerere currently serves 100 design students and hosted visiting Duke students in Summer 2022. After opening the DesignCube, students are able not only to access common tools and material for their prototyping activities, but they can also move freely from one workstation to another to engage, brainstorm and discuss with peers. There is also storage room for prototypes.

Figures 10 and 11: Summer Program Participants with the DesignCube

Students from both schools have had the opportunity to collaborate on biomedical design projects in the Makerere DesignCube (Figure 10). Eight Duke students travelled to Makerere in Summer 2022 through a DukeEngage program, a service-learning program where Duke students travel with Duke faculty for eight weeks over the summer to work with local nonprofits (Figure 11). They worked in integrated Duke-Makerere teams to identify gaps in healthcare delivery that could be solved with the creation of a biomedical device. Prototyping was done in the DesignCube with occasional help from local craftsmen.

Assessment and Initial Observations

Duke DesignCube

Six teams that worked in the DesignCube completed a reflection survey about their initial impressions of the space (Appendix C). This includes four EGR 101 (first-year design) teams, one independent study design team (four undergraduate students), and one research project (undergraduates, graduate students, and two faculty). This is a preliminary tool to gauge how the indoor/outdoor space affected student teams, appropriateness of tools/materials, and attitudes about using the DesignCube.

1. *Tools:* When asked if working in the DesignCube changed their prototyping process compared to the typical makerspace, three (of six) teams responded that they changed the tools used, two teams changed the materials used, and one team significantly changed their design. Two teams reported no effect on prototyping. Teams also reported what tools and materials they used in the DesignCube. Results are summarized in Table 1.

Table 1: Reflection Survey Responses for Tool and Material Use

Tool Category	% of teams that used this category	Material Category	% of teams that used this category
Shears, Saws, Scissors	66.7%	Brainstorming/Drafting (notecards, pens, rulers)	83.3%
Pliers	33.3%	Low Fidelity (paper, pipe-cleaners, cardboard, etc.)	83.3%
Screwdrivers	33.3%	Fasteners (nails, screws, bolts)	50.0%
Clamps	83.3%	Wood (plywood, dowels, boards)	66.7%
Hammer/Mallet	50.0%	PVC	66.7%
Sockets	16.7%	Electronics (Arduino, wires, breadboard, sensors)	33.3%
Measuring Devices/Levels	100%	Recycled/Scavenged Materials	33.3
Power Drill	66.7%	Other Materials	16.7%
Other Tools	16.7%		

2. *Working Outside:* Working outside in Durham, NC is sometimes cold or wet. The authors were concerned that teams would be less productive working outside because of inclement weather. This was not a significant problem, and half the teams cited instances where nice weather made the team more productive. Light was a problem for some teams in the Fall, when the sun set during class time.

3. *Materials:* It was expected that teams would need to order or find project-specific materials, and five (of six) teams used supplemental materials from other makerspaces. (Note: these materials were available in other LMIC settings and in the Makerere DesignCube.) The extra materials needed were not consistent between teams, leading the instructors to conclude that there were no large material gaps in the DesignCube.

While advising student design teams in the Duke DesignCube, instructors and TAs have made thematic observations regarding changes to student learning.

1. EGR101 students spend the first half of the semester in a large, high-tech makerspace. Consequently, transitioning to the DesignCube is somewhat of a letdown. It can be difficult for students to embrace the DesignCube when they have access to many more prototyping options in an adjacent makerspace. Consistent reinforcement from the teaching team has proved valuable in helping students make the transition. As the semester progresses, some teams find alternate benefits to working in the DesignCube (working outside, more space, ability to play music). One team noted in their survey that having their own space aided team bonding.

2. The physical separation between the DesignCube and other makerspaces requires teams to make a conscious choice to seek out supplemental materials. (Ideally, the student teams should not be going to the main space…) If teams cannot find what they need in the DesignCube, they must brainstorm what other materials might be appropriate before looking for them. This sometimes leads to better solutions. A team building a portable neonatal incubator chose to use heated rice packs as the heating element in their solution instead of a complex electrical system. The team also chose not to construct the incubator casing out of acrylic because there was not an effective way to cut it in the DesignCube. Even if teams resort to using tools or materials that are not found in LMIC environments, they do so with the knowledge that this reduces the robustness of their design. Generally, final prototypes from EGR101 teams built in the DesignCube are devoid of inappropriate materials and are successfully manufactured with only DesignCube tools.

Makerere DesignCube

Assessment at the Makerere DesignCube is ongoing. No teams have completed the reflection assessment at this time, though it is planned for future work. Observations by the teaching team have identified several benefits to having the DesignCube. Having a secure storage space for prototypes and in-progress projects is one of the most valuable aspects of the space. Students do not need to take prototypes home or fear them disappearing if left on campus. Collaboration is another observed benefit. Previously, students routinely outsourced work to local craftsmen, whereas this practice has become much less frequent now. With the DesignCube, students work on prototypes in a single space and can collaborate with other teams.

During the summer program with both Duke and Makerere students, Duke students noticed changes in their engineering practice. During informal discussions, Duke students learned to value a wider range of materials and to think out-of-the-box for which materials to use (e.g., using large water bottles as storage containers for screwdrivers). Through the eight-week experience, other students noted that the process of prototyping in Makerere required creativity and perseverance.

Discussion

There are three main takeaways from the parallel development of two shipping container makerspaces: 1) development of an international partnership, 2) unique kind of means-focused makerspace, and 3) challenges of a low-tech makerspace in a high-tech environment.

1. *Development of an International Partnership*: Wettergreen et al. writes a "rallying call for institutions in low- and middle-income countries to seek out partnerships with institutions in high-income areas and work together to cement vibrant maker communities that tackle real-world challenges" [10]. The Duke University DesignCube provides an argument for high-income institutions to also seek out international partners. The DesignCube model is low-cost compared to an entirely new structure and provides customizability for each partner. Container modifications and even the number of containers are different between Duke and Makerere, but the makerspaces are united by the use of a shipping container. The partnership also provided valuable cross-cultural engagement opportunities for students working on the design. An understanding of common making practice at Makerere was necessary to replicate the same environment at Duke. The team at Makerere were also keen to learn about successful makerspaces at Duke while designing their DesignCube. Duke and Makerere have worked together in the past, but this project opened new doors for collaboration. The DukeEngage summer program arose out of the DesignCubes, as well as graduate students from Makerere working as teaching assistants in the first-year design course at Duke.

2. *Unique Means-Focused Makerspace*: In Hira's makerspace framework, the purpose of a means-focused makerspace is derived from the making artifacts in the space [4]. The Duke DesignCube is a means-focused makerspace because it replicates a low-income environment. The space was designed with intentional choices to not include certain tools, materials, and practices. The means artificially constrain the activities in the makerspace. The means also determine the people that interact with the space; only projects intended for low-income environments work in the Duke DesignCube. This is different from a general university makerspace that typically serves a broad range of community members and curricular activities. A low-income means-focused makerspace is limiting in some regards (see #3), but also opens opportunities for unique activities with a low-resource focus. In the global health research project that used the Duke DesignCube, for example, non-engineering students gained familiarity with resource disparities in design and manufacturing capability by using the DesignCube.

3. *Challenges of a Low-Tech Makerspace in a High-Tech Environment*: Purposefully choosing to limit the capability of a new space on a college campus is somewhat against the

momentum of most educational institutions. Procuring a shipping container for the Duke DesignCube required significant coordination and compromise with facilities management. A shipping container contradicts the common aesthetic of most new university spaces. Beyond logistical hurdles, a DesignCube is an inherently low-use space at a high-income university with other makerspaces. Most design teams prefer a larger space with more capability unless constrained by a class or project. Duke University only has two to five first-year design teams completing projects with a low-income context per year. Maintaining a DesignCube requires a healthy awareness of the benefits of a less popular, less 'shiny' makerspace.

Conclusion and Future Work

Over the last four years, the combined team of Duke and Makerere engineers have brought the idea of a shipping container makerspace to life in two unique instantiations. Students at Makerere now have access to a space that allows them to build and test their designs. Duke students engage in more context-conscious design to produce more viable prototypes in LMICs. Both schools benefit from the addition of a modular, durable, and affordable makerspace.

These design spaces will continue to be used on their respective campuses. The team hopes to collaborate with other universities in East Africa or the US to build and test more DesignCubes. Future research will seek to expand on assessment of the spaces. Significant work will be done to quantify the educational impact of a makerspace for Makerere students. Further, additional assessment will be conducted at Duke University. A further goal is to compare outcomes of similar projects made in both spaces and different makerspaces at Duke. The teaching team hopes to run parallel projects in both the high-tech makerspace and the DesignCube at Duke University. This will shed light on differences in prototype success due to learning environment. The title, "Containing Design," encapsulates the mission of these spaces: to contain, in just a shipping container, everything needed to shrink the knowledge and technology gaps experienced by engineering design students across the world.

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Appendix A: List of Tools and Materials in Duke DesignCube

Materials

Fasteners

- Various nails
- Corner braces
- hinges
- Assorted SAE fasteners

Electronics

- Arduino Unos
- Jumper Wires (MM, MF, FF)
- Breadboard Wires
- Motion Sensors
- Temp Sensors
- Protoboards
- Solder
- Flux
- AA, AAA, 9V Batteries
- Various Resistors
- Various Capacitors
- Assorted LEDs

PPE

- Safety glasses
- Earplugs
- Gloves
- Broom/dustpan
- Trashcan
- First Aid Kit

Low Fidelity

- Zip Ties
- Duct Tape
- Masking Tape
- Sand Paper
- Glue
- Two Part Epoxy
- Index Cards
- Rope
- Yarn and string
- Cardboard
- Sharpies
- Straws
- Whiteboard and markers
- Magnetic Tape
- Plastic Tubing
- Stapler
- Rubber Bands
- Recycled bottles, old containers, scrap material

Medium Fidelity

- PVC and PVC connectors
- 2x4s
- Plywood sheets
- Dowels
- Wood Glue
- Scrap Wood
- PVC glue

Sewing

- Scrap cloth
- Scissors
- Sewing kit with thread & needles
- Sewing pins
- Sewing machine

Tools

- Adjustable wrenches
- Socket Sets
- Ratchets and Drive Extensions
- Hammers
- Mallets
- Screwdrivers
- Clamps
- Files
- Chisels
- Measuring Devices
- (Tape Measures, Meter-sticks, Rulers, Calipers)
- Levels
- Saws
- Pliers
- Wire Stripper
- Allen Keys
- Box Cutters
- Scrapers
- Glue Gun
- Powered Drill
- Crescent wrenches

- Drill Bits
- Vise
- Tabletop Drill Press

Appendix B: Partial List of Tools and Materials in Makerere DesignCube

Materials

- Screws
- Ear plugs
- Wrenches
- Multimeter
- Soldering gun (hot iron)
- Desoldering pump
- Solder wires
- Electric wires
- Cable ties
- Filters

Tools

- Tape measure
- Drive sockets set
- Allen keys sets
- Pliers
- Saws
- Knives/ blades
- Ratchet wrench
- Filer
- Wire cutters
- Scissors
- Torch
- Terminal holders
- Height level
- Metallic ruler
- Hammer
- 3D printer (PRUSA i3 MK3S) + filament
- Sewing machine (Gemini)
- Digital indicator
- Printer
- Pulse meters
- Thermometers
- Laryngoscope
- Clock timer
- Proact probes
- Drill
- Vice
- Clamp
- Set of cutters
- Clippers
- Magnetic bit drivers
- Engraving machine
- Head light
- Syringe
- Eye goggles

Appendix C: Duke DesignCube Team Survey

DesignCube Survey Fall 2022

Start of Block: General Information

Q22 Hello! Welcome to the Container Use Survey for Fall 2022. Please fill out this survey every week. Discuss responses as a team and submit one survey per team.

Q1 Select the Lab Date

▼ Week of October 10-14 (2) ... Week of December 5-9 (14)

Q2 What is your team name?

Q3 Where were you working this week?

- Inside the Container (1)
- Outside the Container (2)
- Both (3)
- Neither (4)

Q4 How did the weather/lighting conditions affect your team's productivity this week?

- No effect (1)
- I was less productive than in the Pod (2)
- I was more productive than in the Pod (3)

Display This Question:

If How did the weather/lighting conditions affect your team's productivity this week? = I was more productive than in the Pod

Q5 What was the weather and how did it make your team more productive?

Display This Question:

If How did the weather/lighting conditions affect your team's productivity this week? = I was less productive than in the Pod

Q6 What was the weather and how did it reduce your team's productivity?

Start of Block: Tools and Materials

Q7 Please select all the types of materials your team used this week.

- ▢ Brainstorming/Drafting (notecards, pens, rulers) (1)
- ▢ Low Fidelity (paper, pipe-cleaners, cardboard, etc.) (2)
- ▢ Fasteners (nails, screws, bolts) (3)
- ▢ Wood (plywood, dowels, boards) (4)
- ▢ PVC (5)
- ▢ Electronics (arduino, wires, breadboard, sensors) (6)
- ▢ Recycled/Scavenged Materials (7)
- ▢ Other (list below) (8)

Display This Question:

If Please select all the types of materials your team used this week. = Other (list below)

Q8 Please list the other materials you used.

Q9 Please select all the tools your team used this week.

- [ ] Shears, Saws, Scissors (1)
- [ ] Pliers (2)
- [ ] Screwdrivers (3)
- [ ] Clamps (4)
- [ ] Hammer/Mallet (5)
- [ ] Sockets (6)
- [ ] Measuring Devices/Levels (7)
- [ ] Power Drill (8)
- [ ] Other (list below) (9)

Display This Question:

If Please select all the tools your team used this week. = Other (list below)

Q10 Please list other tools used that are not listed above.

Q11 Did you go to the Pod for any tools or materials this week?

- [ ] Yes, we got materials from the Pod (1)
- [ ] Yes, we got tools (2)
- [ ] Yes, we got both (3)
- [ ] No (4)

Display This Question:

If Did you go to the Pod for any tools or materials this week? = Yes, we got both

Or Did you go to the Pod for any tools or materials this week? = Yes, we got tools

Q12 What tools did you use from the Pod?

Display This Question:

If Did you go to the Pod for any tools or materials this week? = Yes, we got materials from the Pod

Or Did you go to the Pod for any tools or materials this week? = Yes, we got both

Q13 What materials did your team use from the Pod?

Start of Block: Misc. Questions

Q14 Please rate how difficult it was to find things in the container.

	Extremely easy	Somewhat easy	Neither easy nor difficult	Somewhat difficult	Extremely difficult
	0 1	2 3	4 5 6	7 8	9 10
Click to write Choice 1 ()					

Q15 Did you or a teammate feel unsafe at any time while working this week?

○ Yes (1)

○ No (2)

○ I prefer not to say (3)

Display This Question:

If Did you or a teammate feel unsafe at any time while working this week? = Yes

Q16 What made you feel unsafe?

Display This Question:

If Did you or a teammate feel unsafe at any time while working this week? = I prefer not to say

Q17 Your safety is important. Would you like an instructor to reach out to you to discuss safety during class?

- ○ Yes (1)
- ○ No (2)
- ○ Maybe (3)

Q18 How did working in the container change your design/prototyping?

- ▢ No effect this week (1)
- ▢ We changed materials used (2)
- ▢ We used different tools/machines to prototype (3)
- ▢ We majorly changed our design (4)

Display This Question:

If How did working in the container change your design/prototyping? = We majorly changed our design

Or How did working in the container change your design/prototyping? = We changed materials used

Or How did working in the container change your design/prototyping? = We used different tools/machines to prototype

Q19 Please explain further.

Q20 Please share any additional thoughts about your container experience! (including but not limited to specific challenges, suggested improvements, random ideas, etc.)

Q21 Click the Next button to submit this survey. Thank you!